NEWS-G:
Search for low-mass WIMPS with Spherical Proportional Counters

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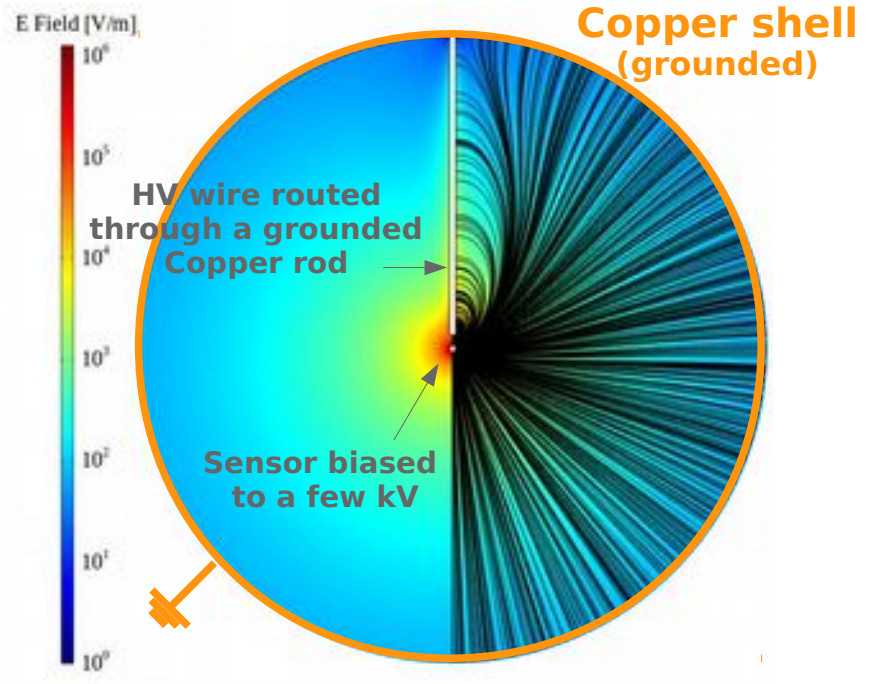
UCLA Dark Matter conference
February 23rd 2018

Outline

- Spherical Proportional Counters (SPCs)
- SEDINE at LSM
- Latest limits on low mass DM with SEDINE
- Status of NEWS-G at SNOLAB

SPC

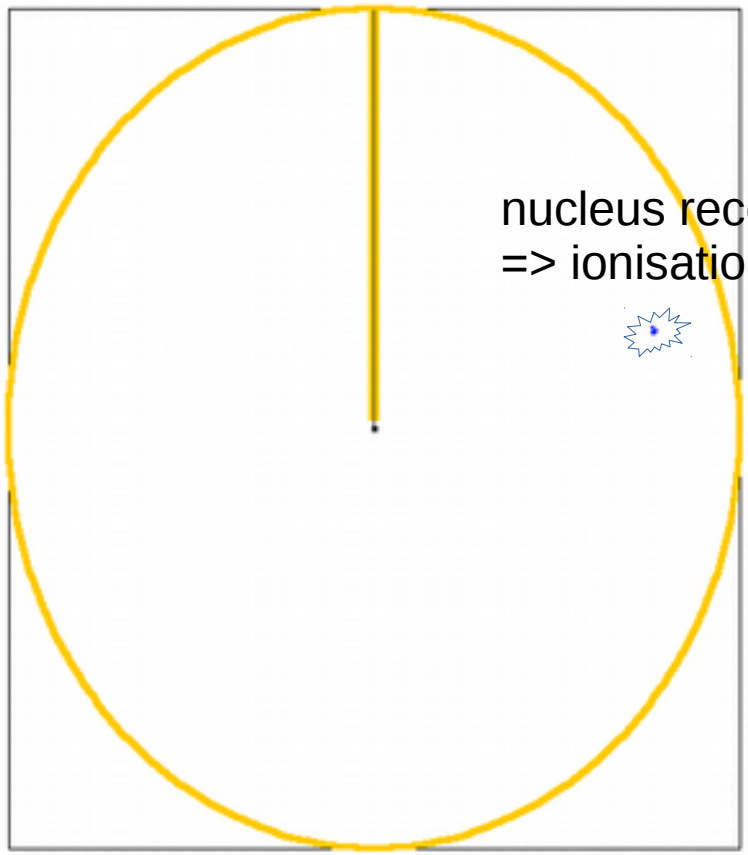


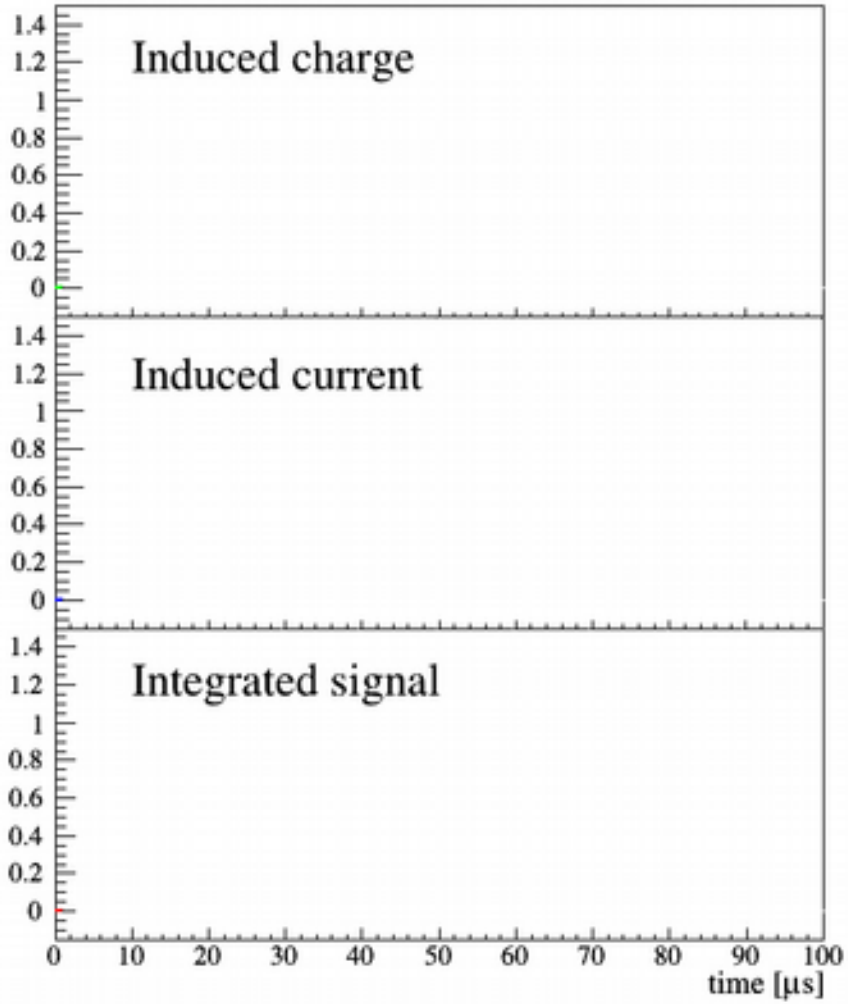
- Gaseous propotional counter
  - Copper sphere
  - Central ball with HV
- Very low capacitance
  - <1pF
- Drifting electrons from ionisation
- Light gas optimal for low mass WIMPs

Vessel
60 cm ∅ NOSV Copper

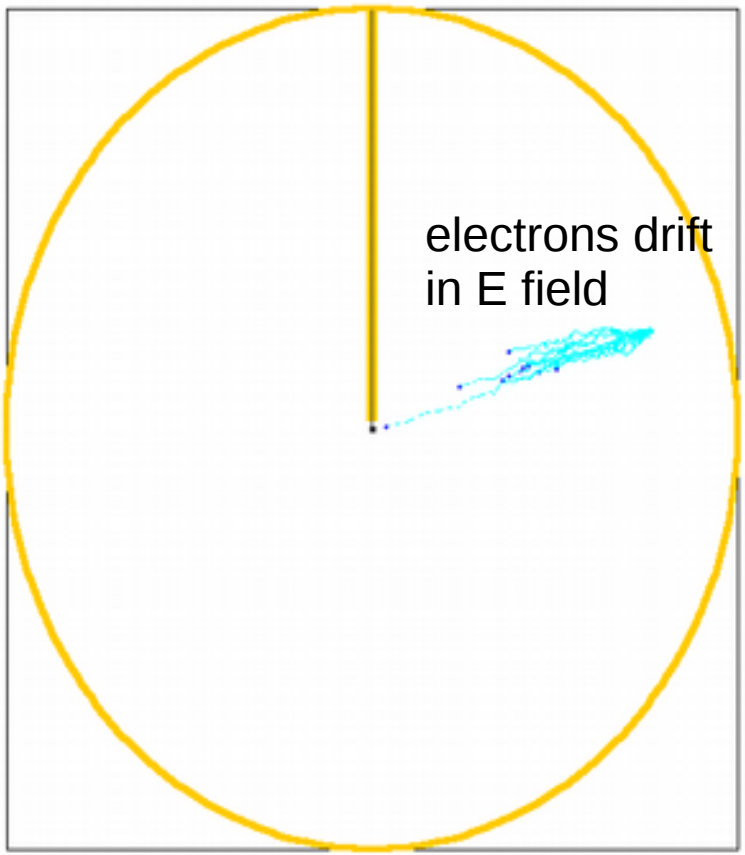
Sensor
6.3 mm ∅

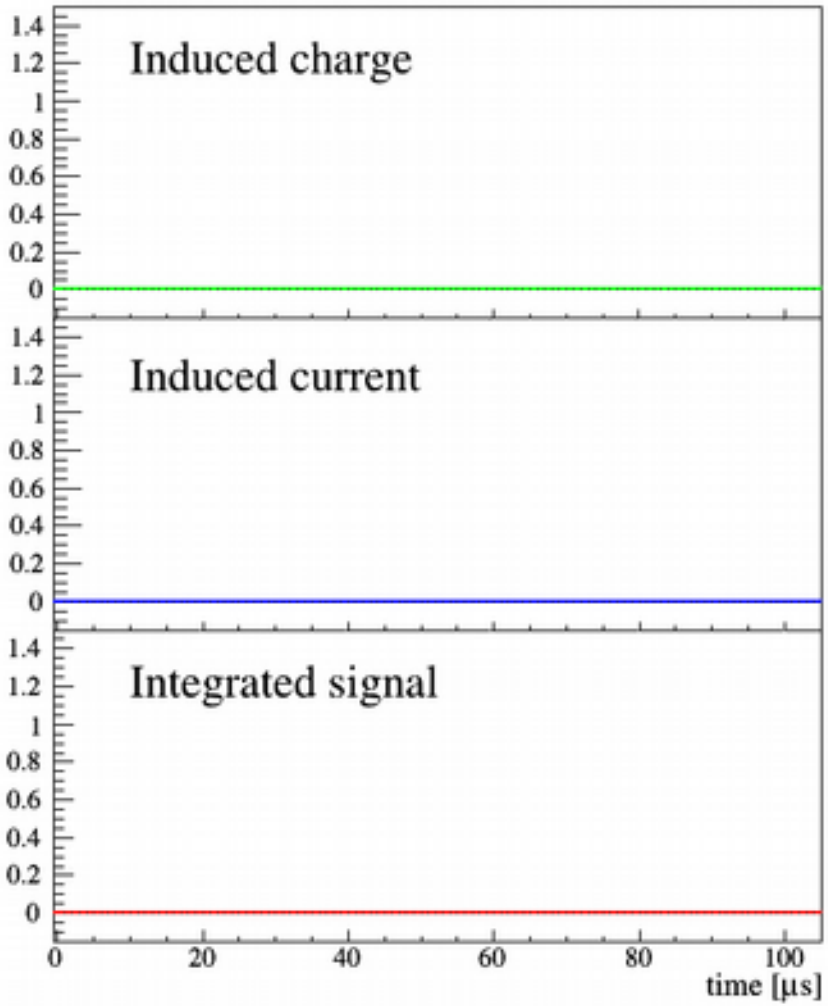
SPC signal


nucleus recoil
=> ionisation of gas

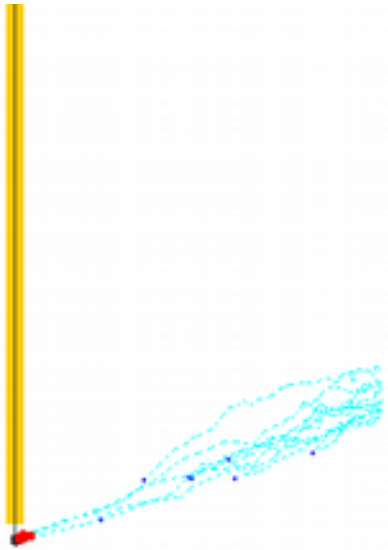

Induced charge
Induced current
Integrated signal
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
10
20
30
40
50
60
70
80
90
100
time [µs]

SPC signal

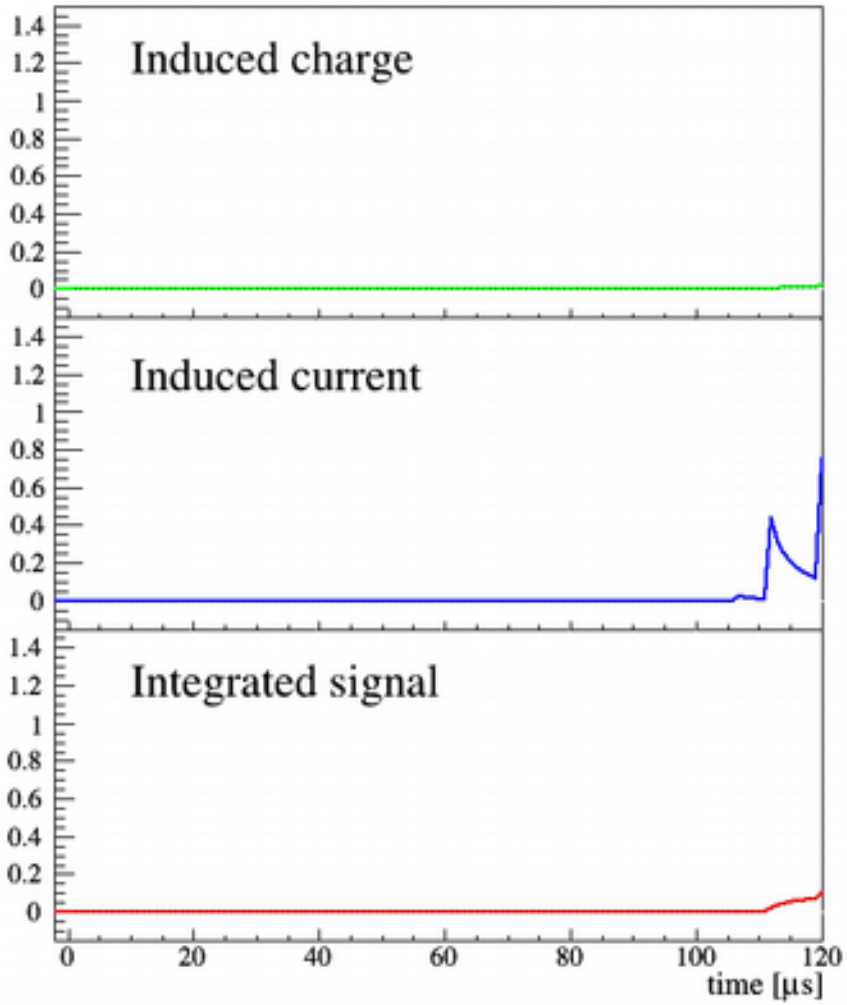

electrons drift
in E field


Induced charge
Induced current
Integrated signal
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
time [µs]

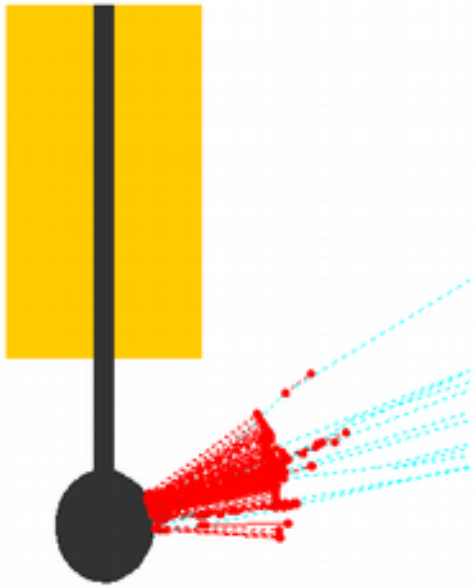
SPC signal



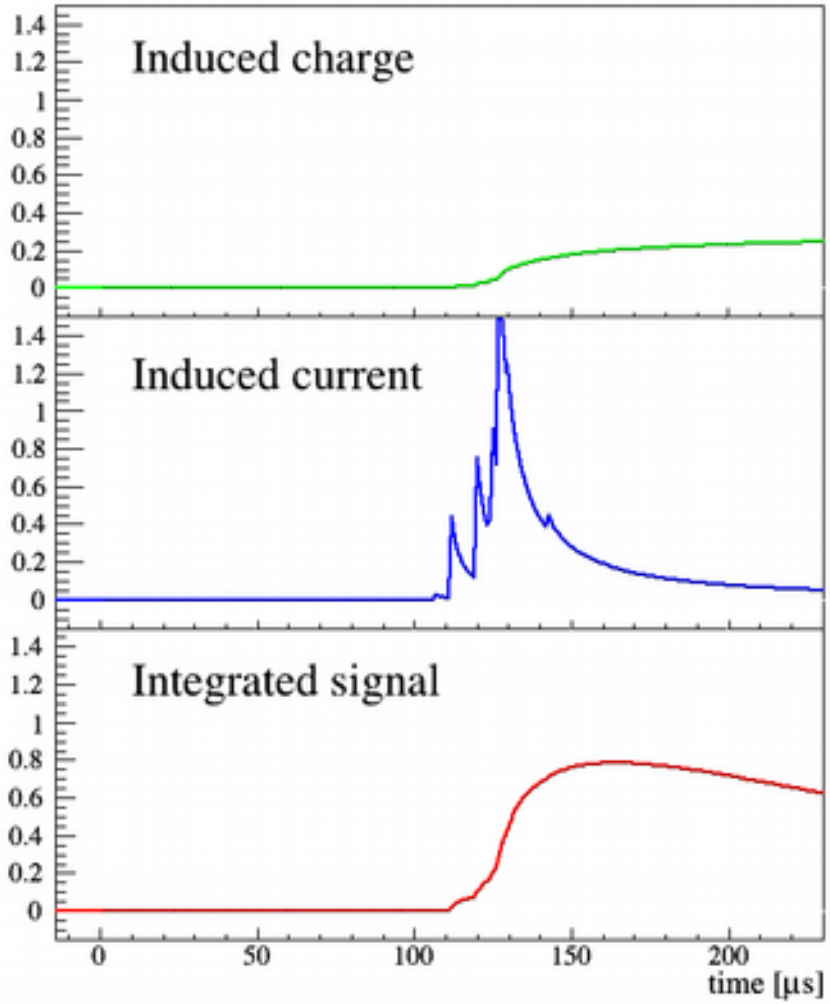
avalanche in high field near sensor



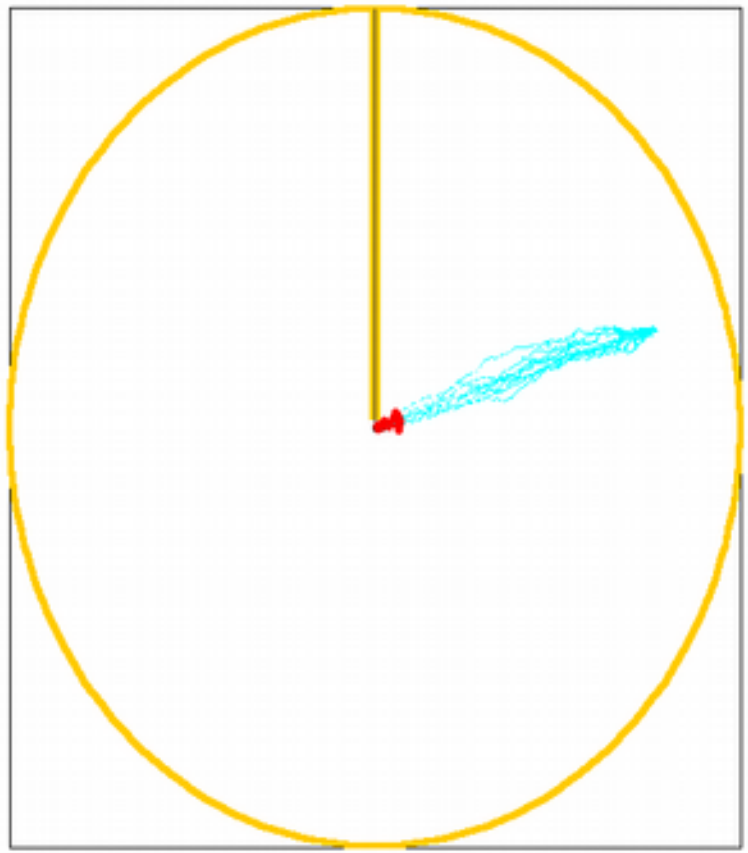
SPC signal

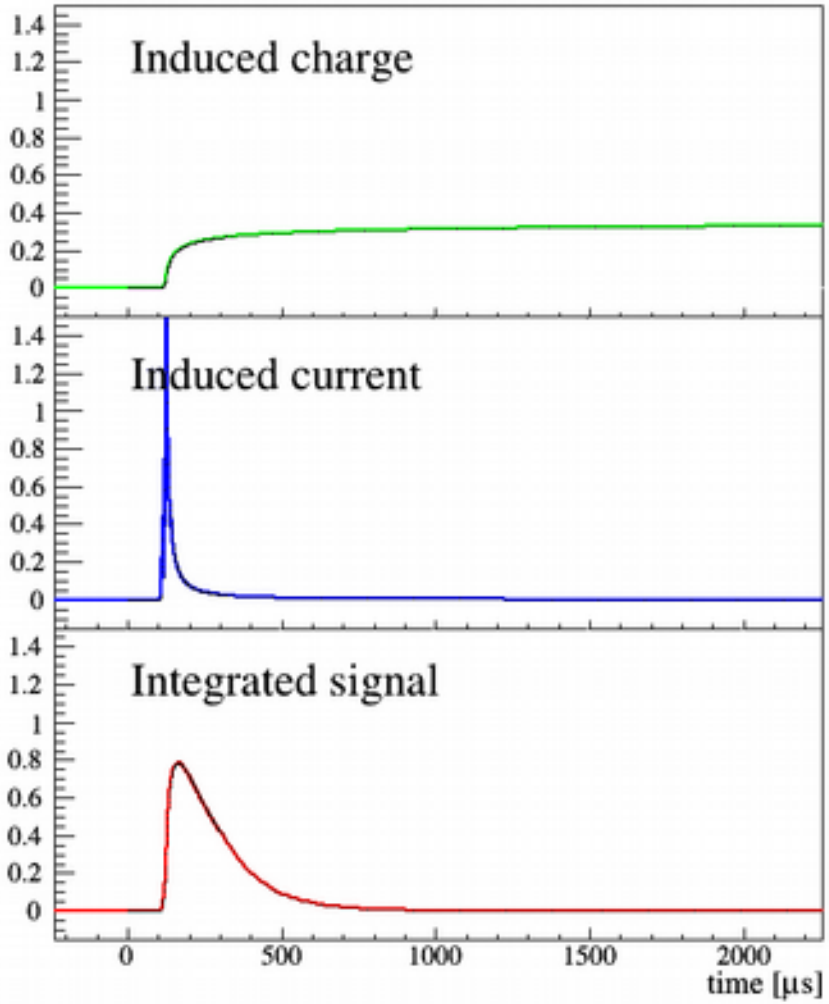


Signal induced by ions drifting back

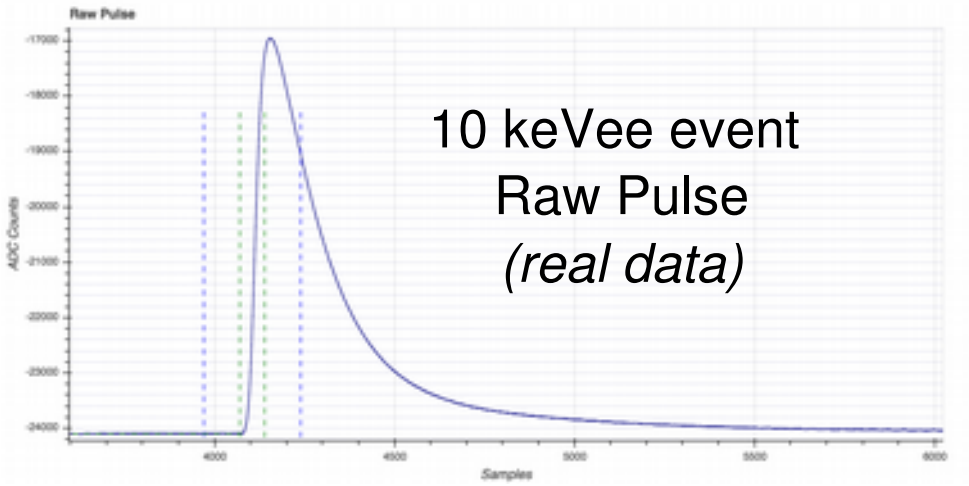


SPC signal

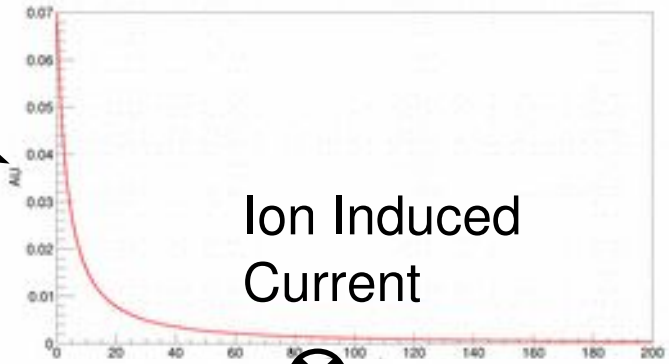



Induced charge
Induced current
Integrated signal
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
500
1000
1500
2000
time [µs]

Pulse treatment

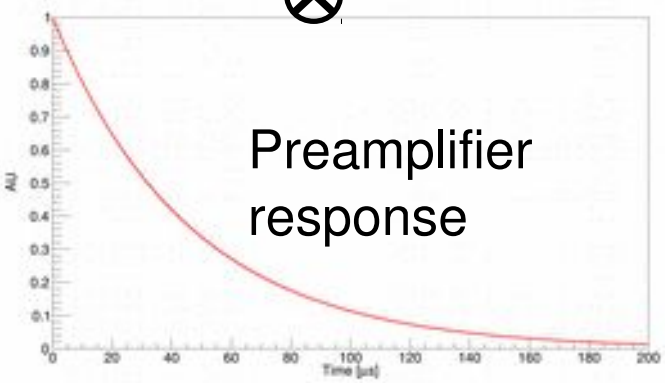


10 keVee event
Raw Pulse
(real data)

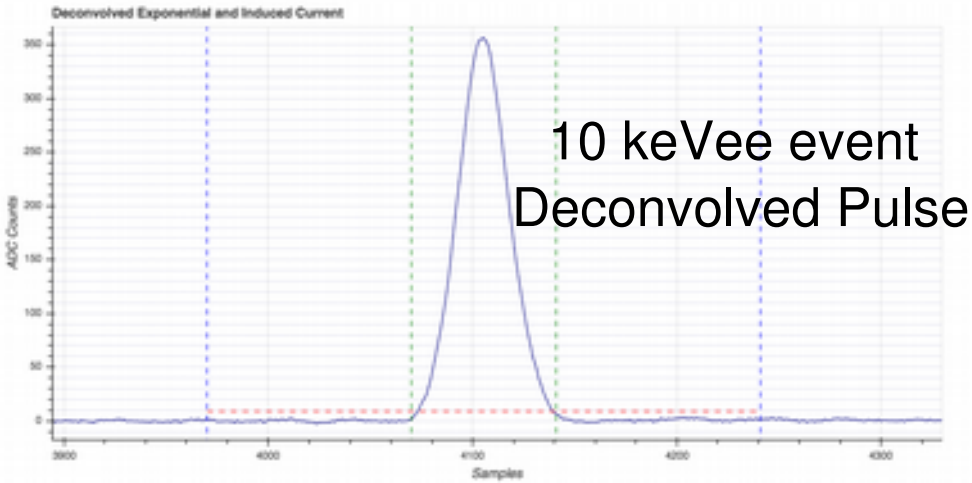


Ion Induced
Current

⊗

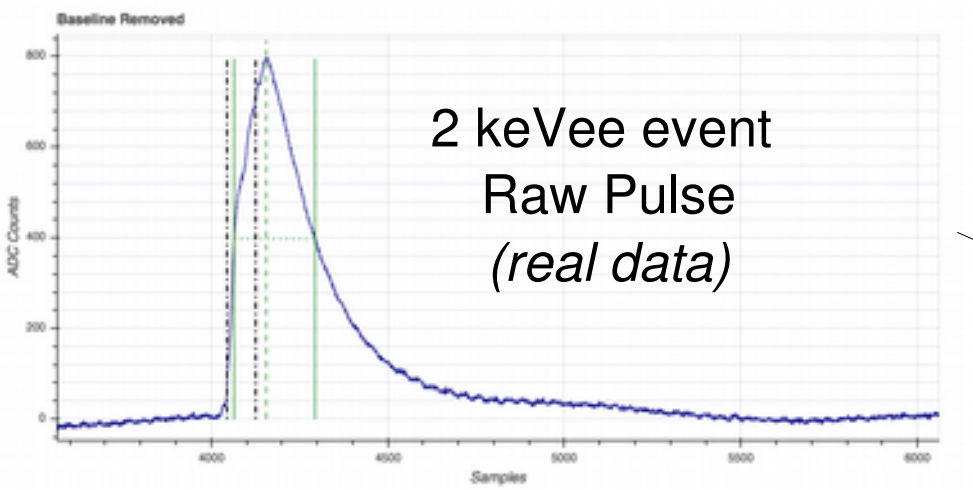


Preamplifier
response

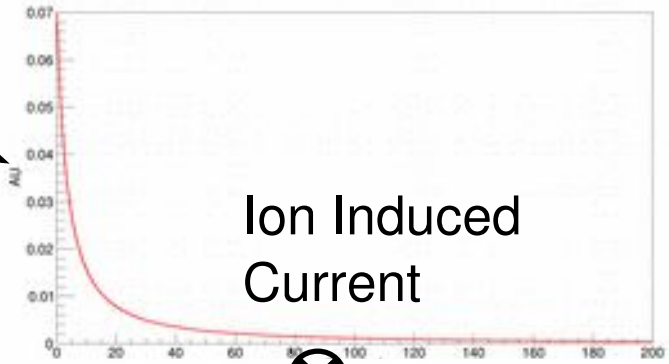


10 keVee event
Deconvolved Pulse

Pulse treatment

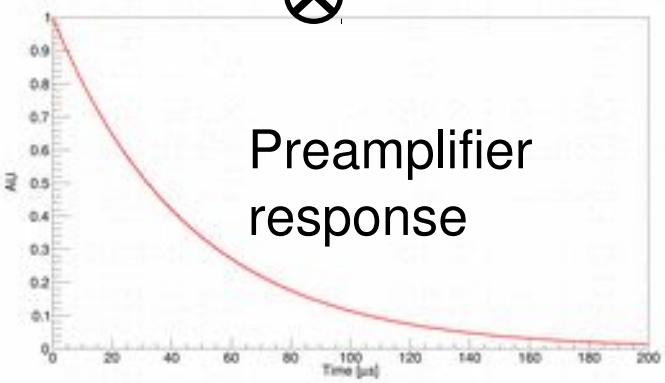


2 keVee event
Raw Pulse
(real data)

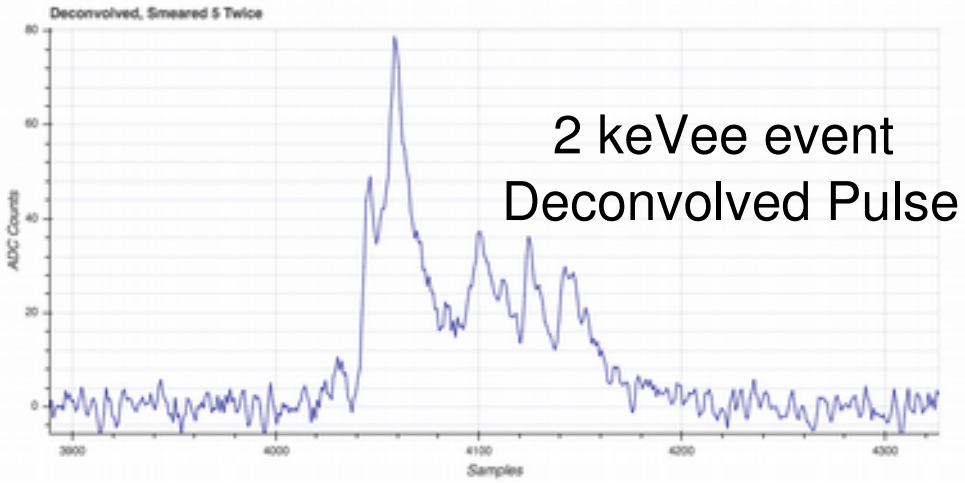


Ion Induced
Current

⊗



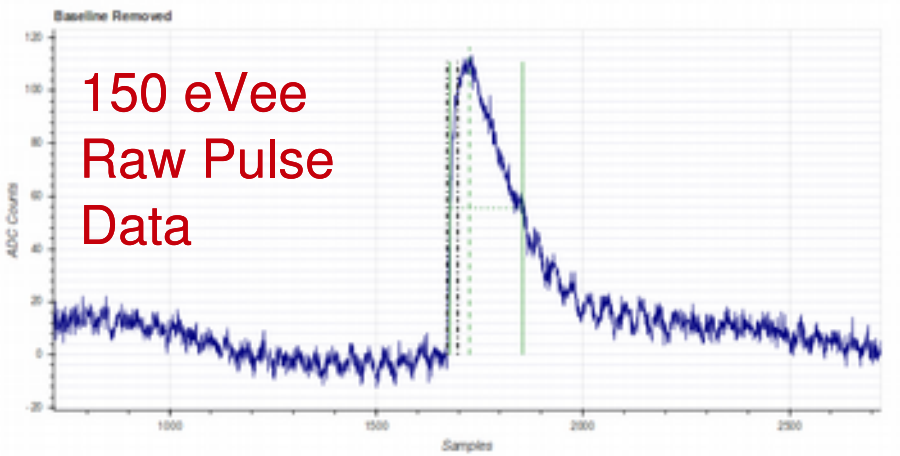
Preamplifier
response

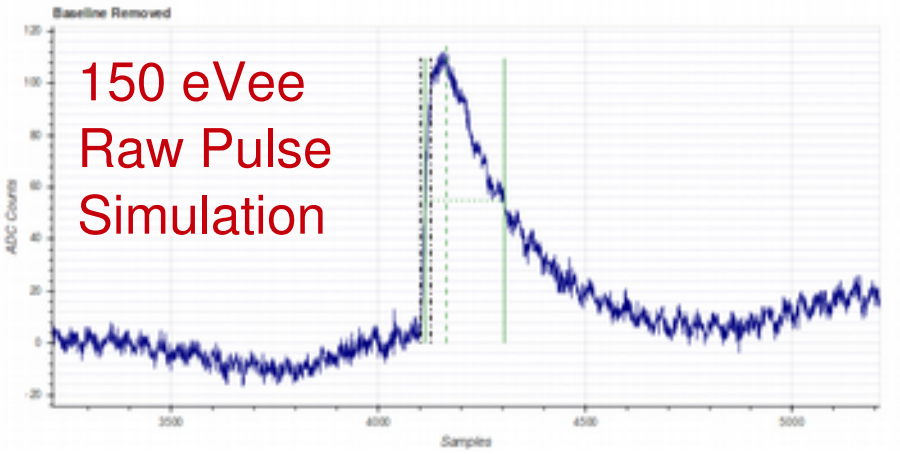


2 keVee event
Deconvolved Pulse

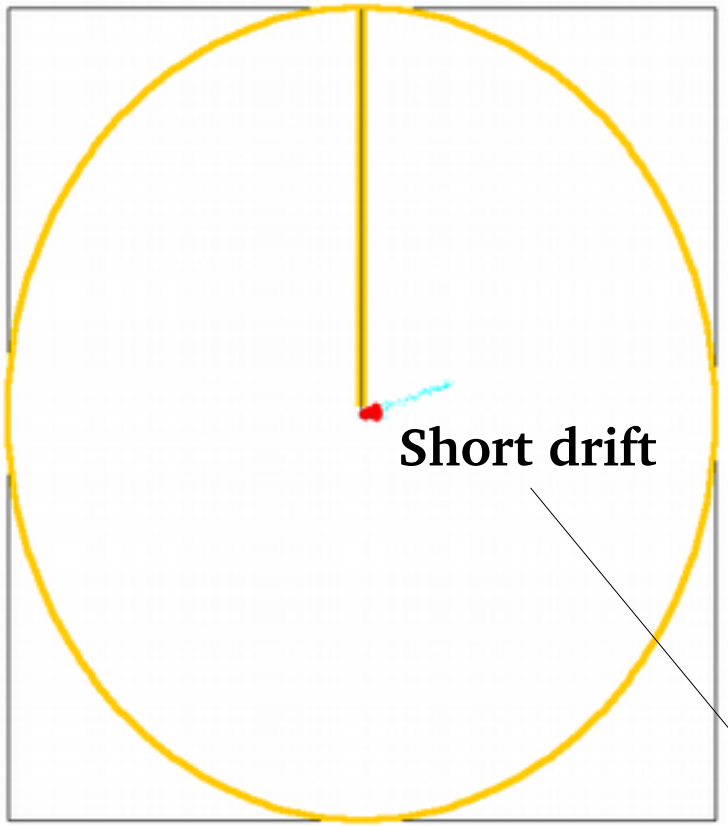
Simulation

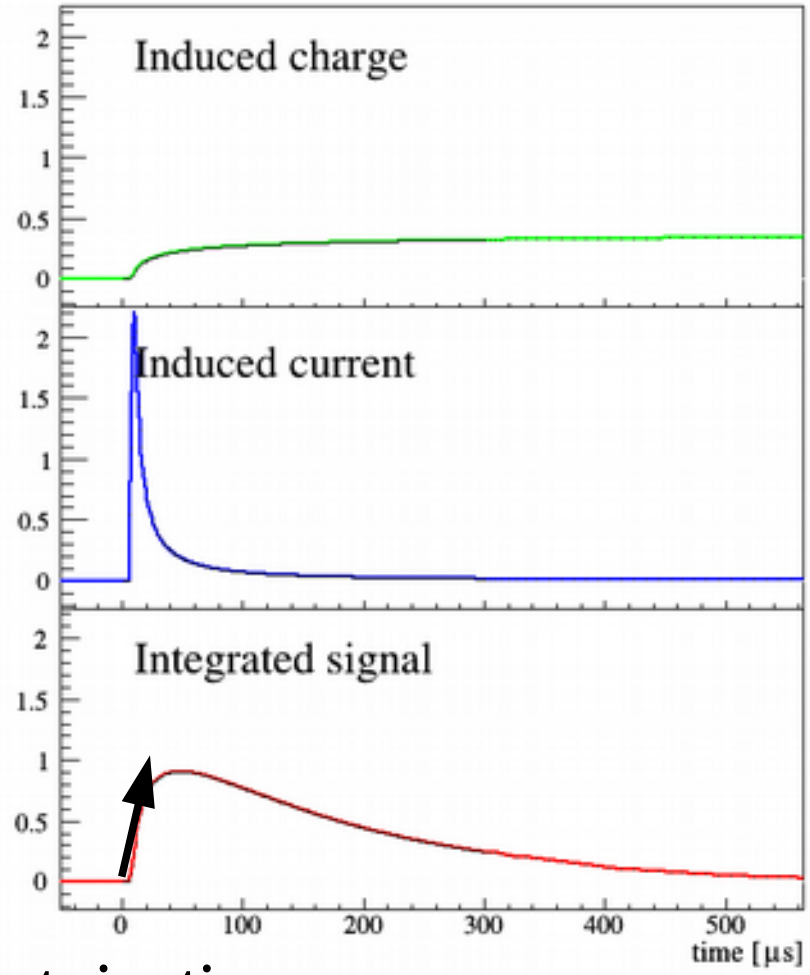
- Drift of individual electrons
  - COMSOL, Magboltz
- Quenching:
  - SRIM, parametrisation
- Avalanche
  - Polya distribution (Garfield++)
- Simulated amplifier pulses
- Noise from data templates
- Same processing as real pulses





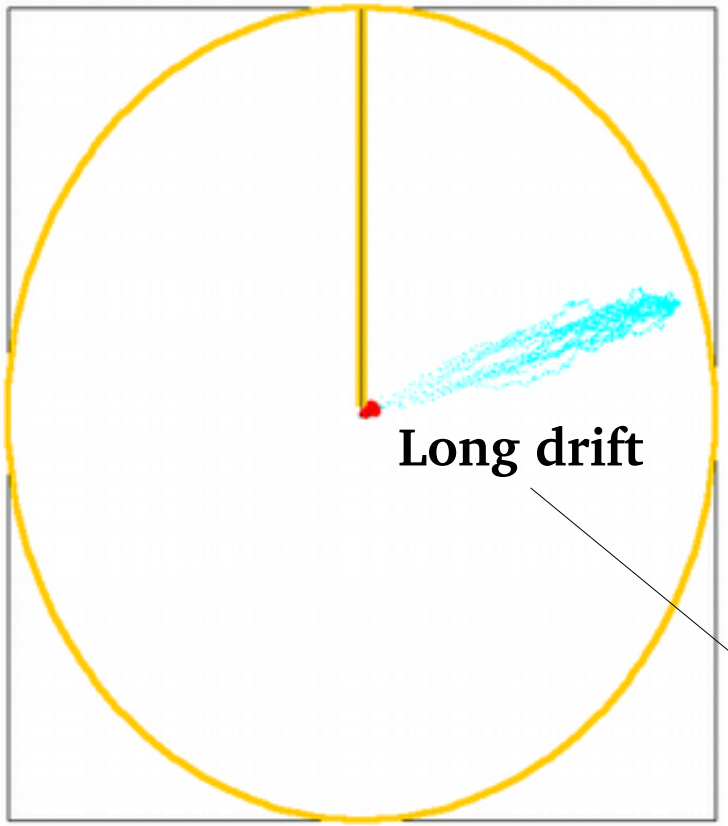
Event discrimination: Rise time

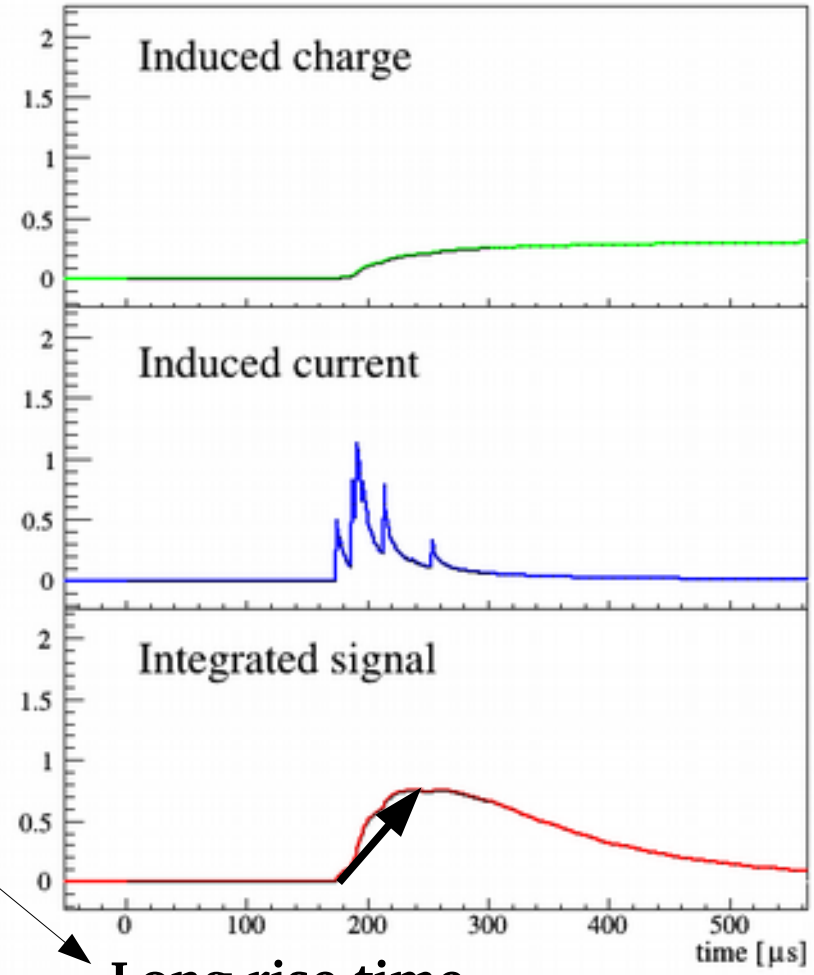




Short rise time

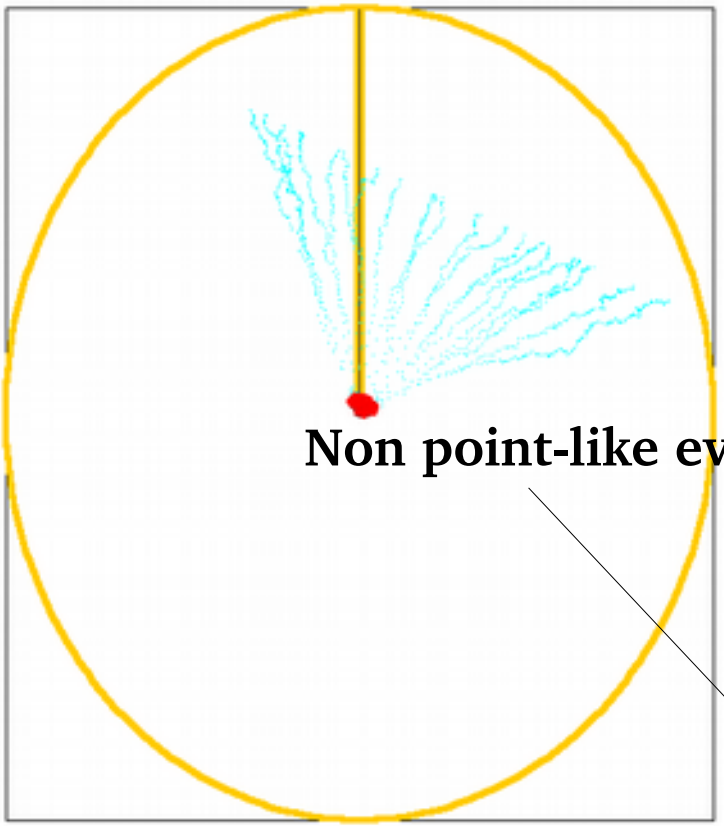
Event discrimination: Rise time



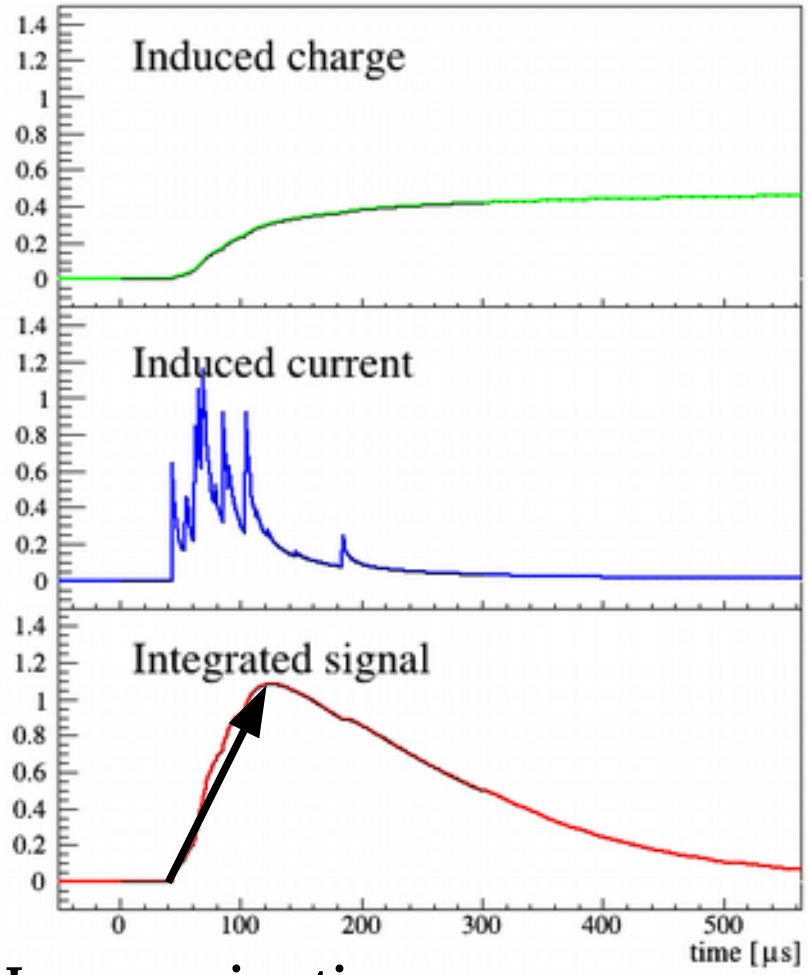


Long rise time

Event discrimination: Rise time



Non point-like event



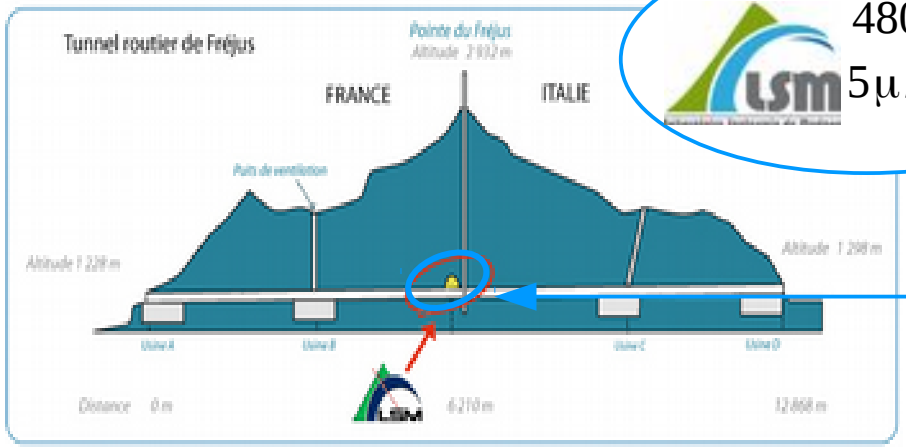
Loonng rise time

Results with SEDINE

(NEWS-G at LSM)

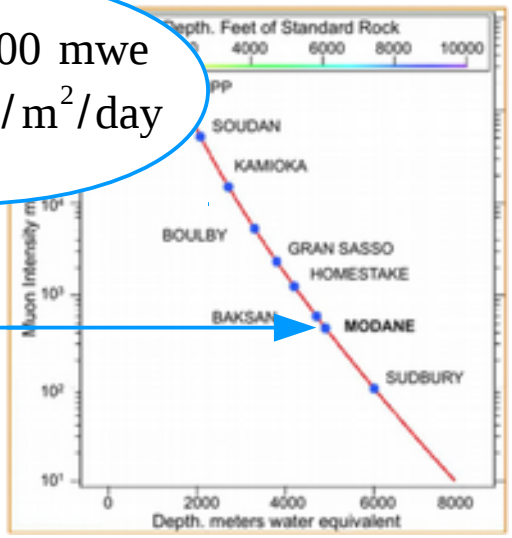
SEDINE at LSM

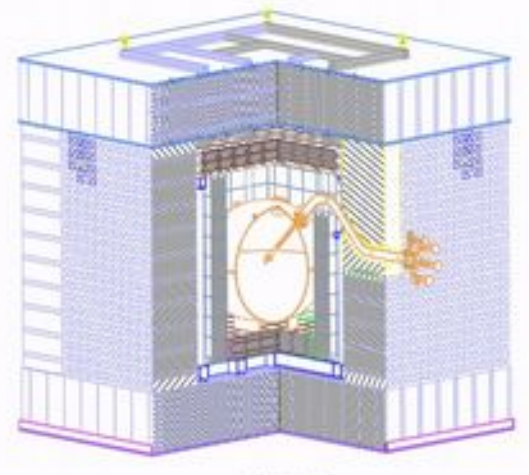
Laboratore Souterrain de Modane



4800 mwe

$5\mu/m^2/day$





Shielding

30cm PE, 10-15cm Pb, [3-8]cm Cu

Vessel

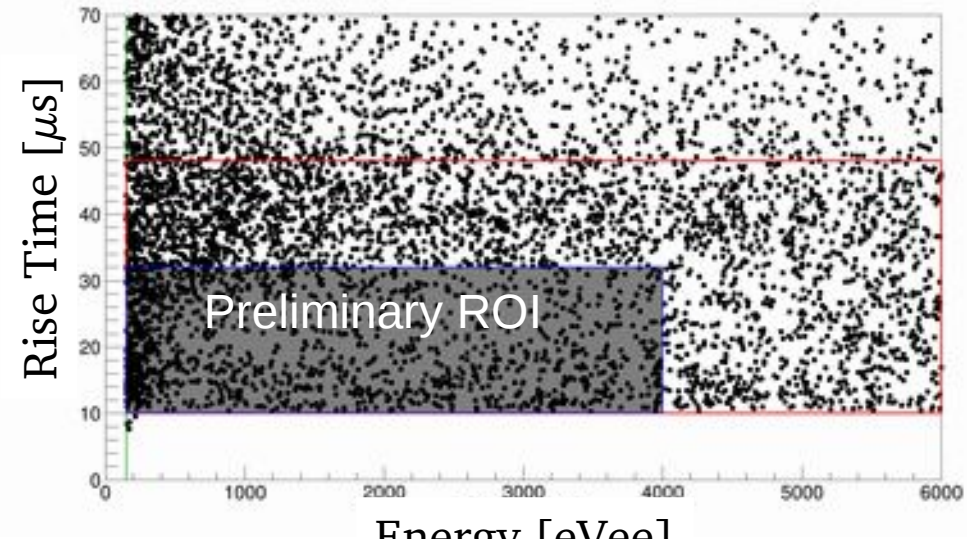
60 cm ∅ NOSV Copper

Sensor

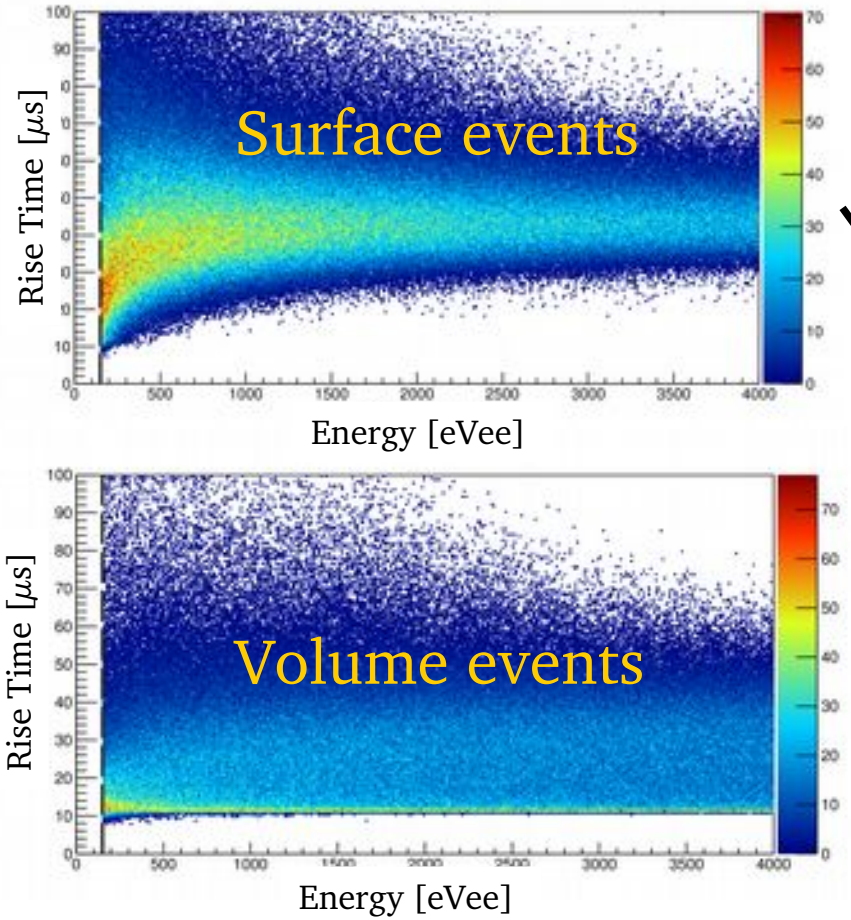
6.3 mm ∅

9.7 kg.days of exposure with **Neon+0.7 % CH_4 @ 3.1 bars**

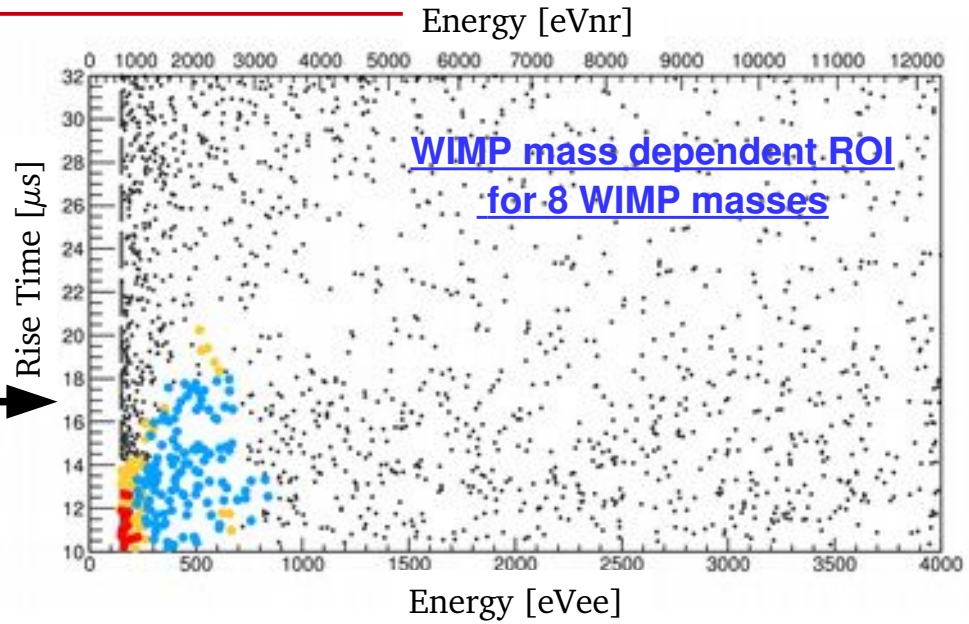
~280 g target mass, operated for **42.7 days** in **sealed mode**



Data analysis



BDT



1620 events recorded in the preliminary ROI :

Fail any of the BDT cuts

pass the BDT cut for 0.5 GeV/c2 : 15 events

pass the BDT cut fot 16 GeV/c2 : 123 events

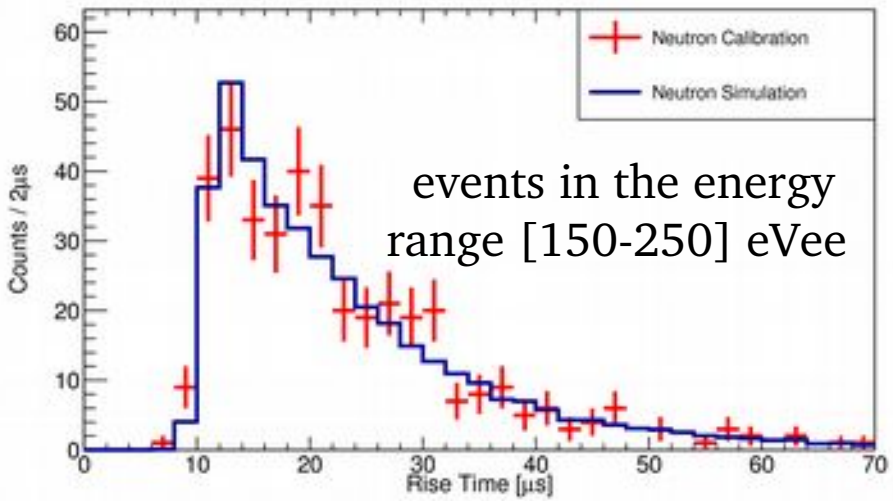
pass the BDT cut for other masses

Analysis methodology robust against background mis-modeling:
If BDT trained with inaccurate bkg models, ROI not optimized

Simulation Validation

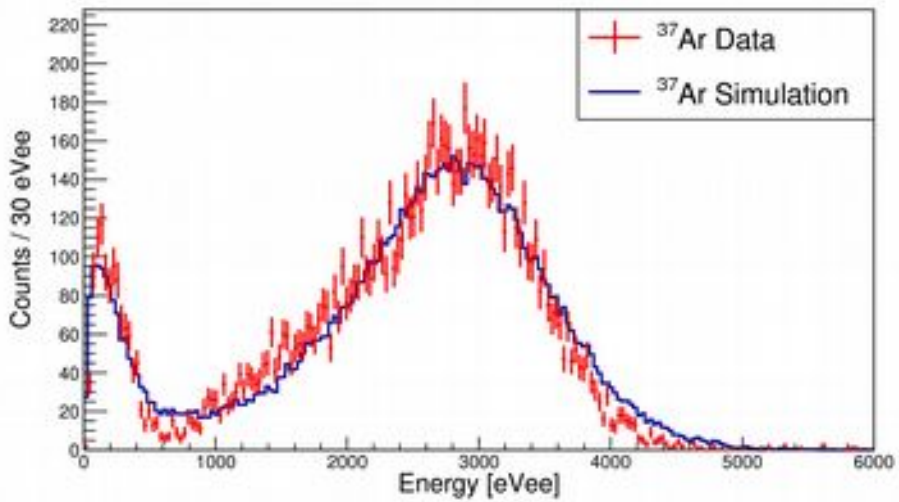
Am-Be neutron source

Nuclear recoils
homogeneously distributed
in the volume



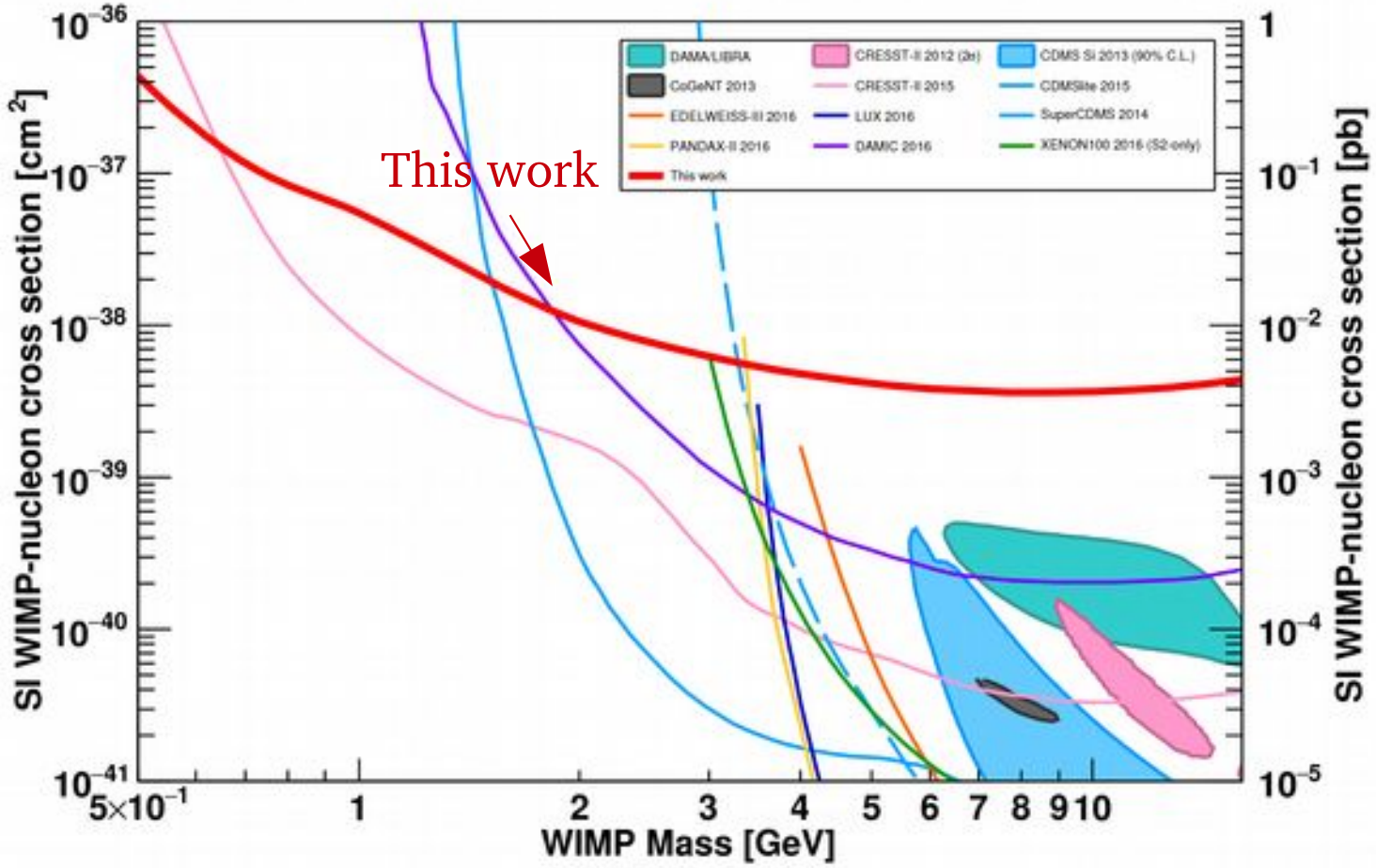
^{37}Ar gas added to the mixture

2.82 keV and 270 eV X-rays from
the electron capture
in the K- and L-shells respectively



The overall agreement allows us to confidently derive our sensitivity from simulated WIMP events

First results from NEWS-G at LSM

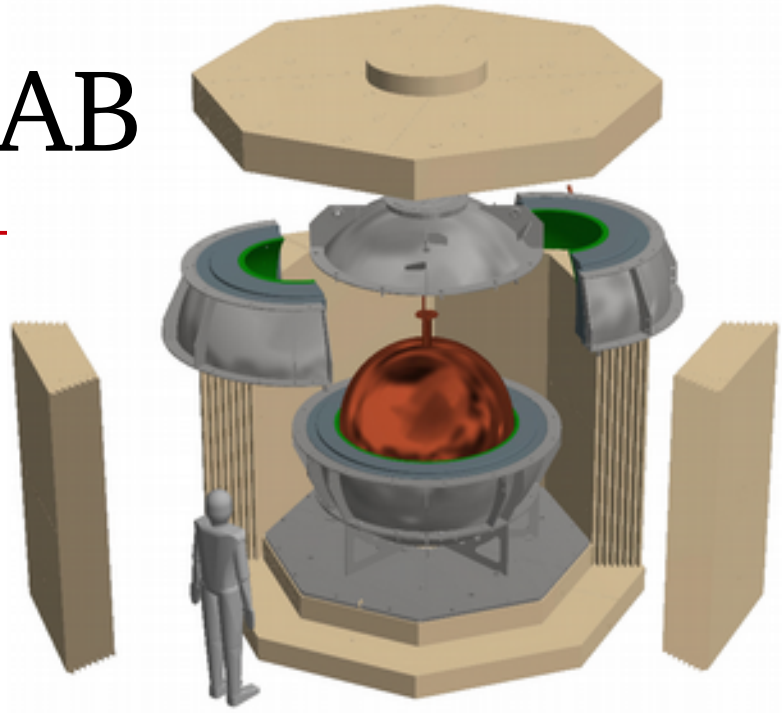


Q. Arnaud et al. (NEWS-G), Astropart. Phys. 97, 54 (2018) doi: 10.1016/j.astropartphys.2017.10.009

Next step:

NEWS-G at SNOLAB

NEWS-G at SNOLAB



Copper vessel (140 cm Ø, 12 mm thick)

- Low activity copper (C10100)
  - 7 to 25 μBq/kg Th
  - 1 to 5 μBq/kg of U
- Electropolishing cleaning & Electroplating

Compact shielding

- 40 cm PE + Boron sheet
- 22 cm VLA (1 Bq/kg ^{210}Pb)
- 3 cm archeological lead
- Air tight SS envelope to flush pure N (against Rn)

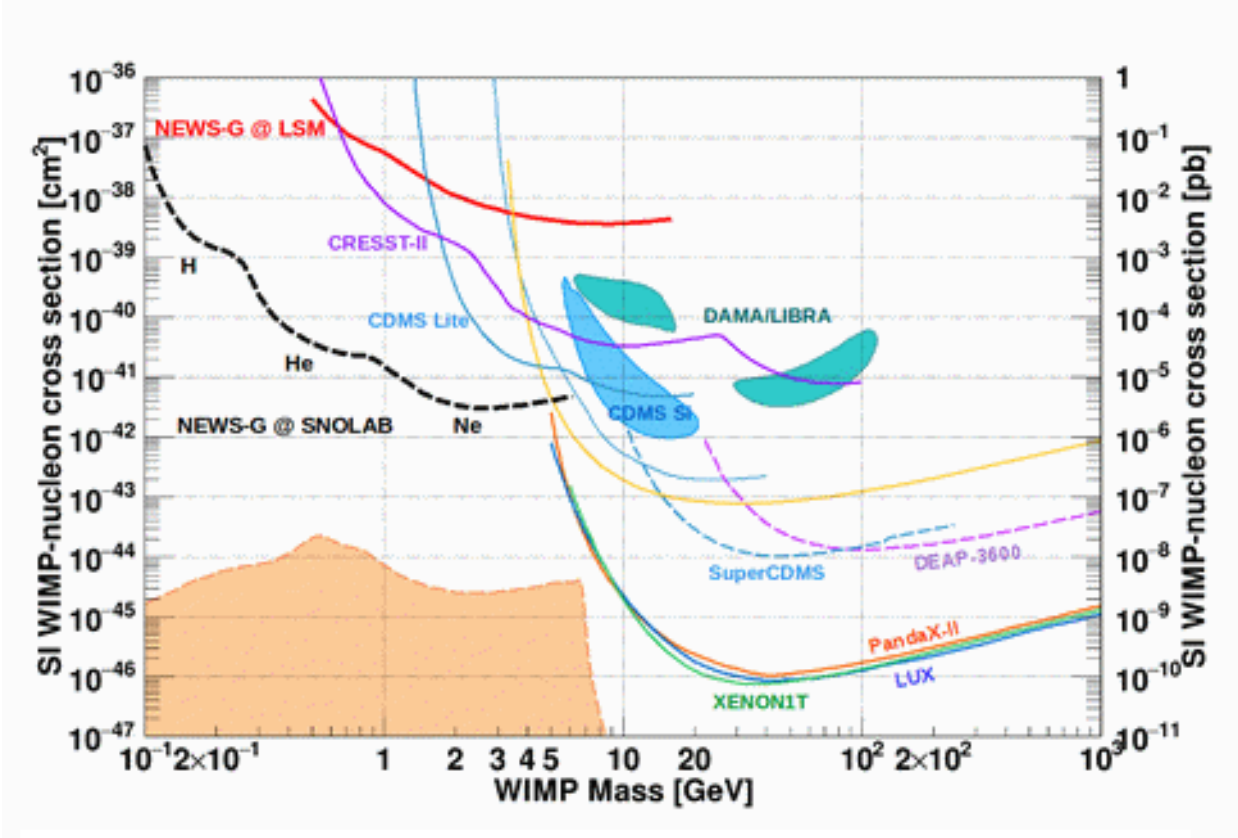
Hemispheres built in France, stored at LSM before welding

Glove box for Radon-free rod installation

Installation in Cube Hall at SNOLAB end of 2018

NEWS-G at SNOLAB

- Bigger, cleaner
- Better simulation
- Quenching factor measurements at TUNL
- *High expectations!*



100 kg.days, 200eVee ROI above threshold @ 1 electron. (Not accounting for sensitivity improvement from resolution effects and RT cuts)

the Collaboration

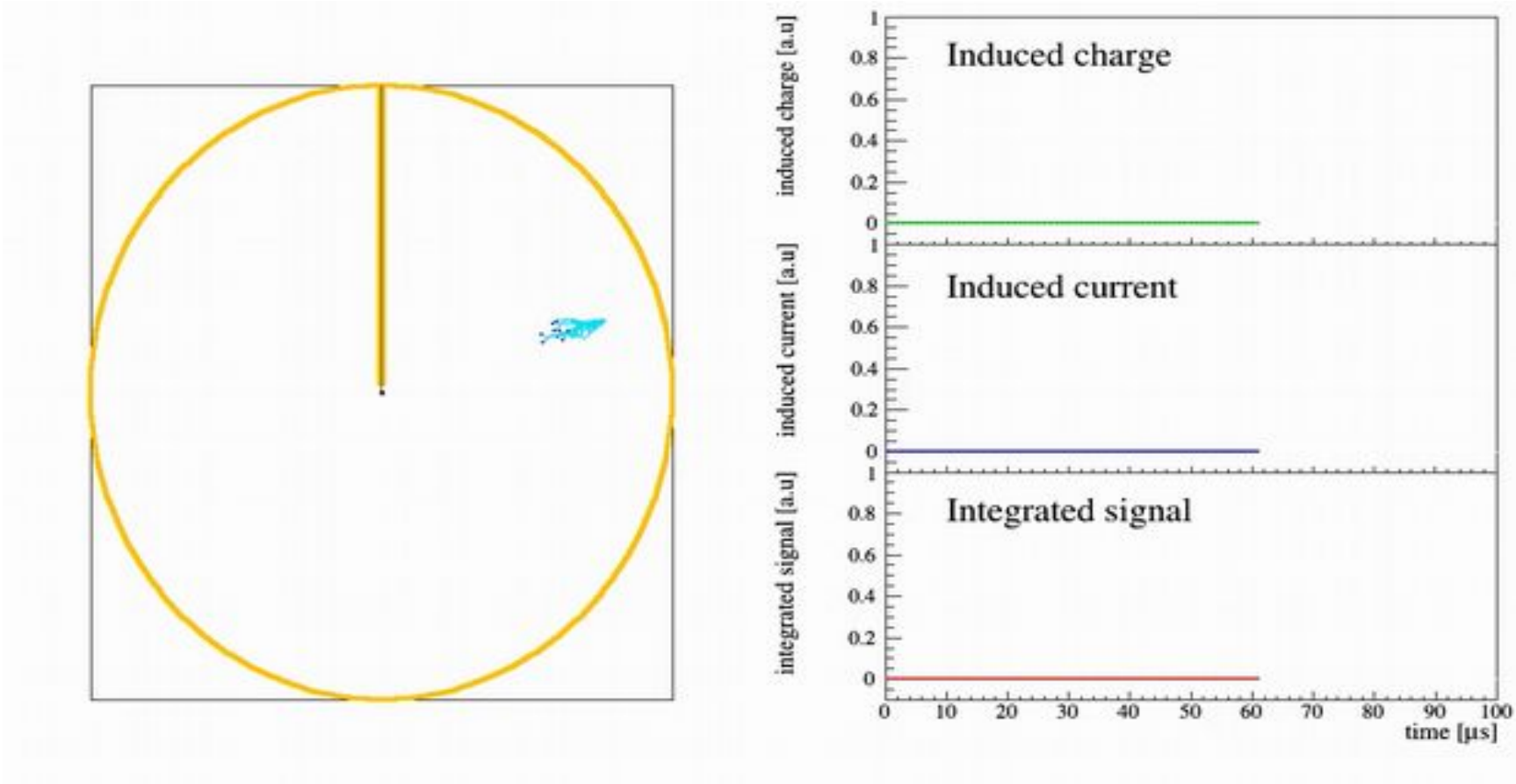
thanks you for your attention

- **Queen's University Kingston –** G Gerbier**,** P di Stefano, R Martin, G Giroux, T Noble, D Durnford, S Crawford, M Vidal, A Brossard, F Vazquez de Sola, Q Arnaud, K Dering, J Mc Donald, M Clark, M Chapellier, A Ronceray, P Gros, J Morrison, C Neyron
  - Copper vessel and gas set-up specifications, calibration, project management
  - Gas characterization, laser calibration, on smaller scale prototype
  - Simulations/Data analysis
- **IRFU** (Institut de Recherches sur les Lois fondamentales de l'Univers)**/CEA Saclay** -I Giomataris, M Gros, C Nones, I Katsioulas, T Papaevangelou, JP Bard, JP Mols, XF Navick,
  - Sensor/rod (low activity, optimization with 2 electrodes)
  - Electronics (low noise preamps, digitization, stream mode)
  - DAQ/soft
- **LSM** (Laboratoire Souterrain de **Modane**), IN2P3, U of Chambéry **-** F Piquemal, M Zampaolo, A DastgheibiFard
  - Low activity archeological lead
  - Coordination for lead/PE shielding and copper sphere
- **Thessaloniki University –** I Savvidis, A Leisos, S Tzamarias
  - Simulations, neutron calibration
  - Studies on sensor
- **LPSC (**Laboratoire de Physique Subatomique et Cosmologie) **Grenoble** - D Santos, JF Muraz, O Guillaudin
  - Quenching factor measurements at low energy with ion beams
- **Pacific National Northwest Lab–** E Hoppe, DM Asner
  - Low activity measurements, Copper electroforming
- **RMCC (**Royal Military College Canada**) Kingston –** D Kelly, E Corcoran
  - 37 Ar source production, sample analysis
- **SNOLAB –Sudbury –** P Gorel
  - Calibration system/slow control
- **University of Birmingham –** K Nikolopoulos, P Knight
  - Simulations, analysis, R&D

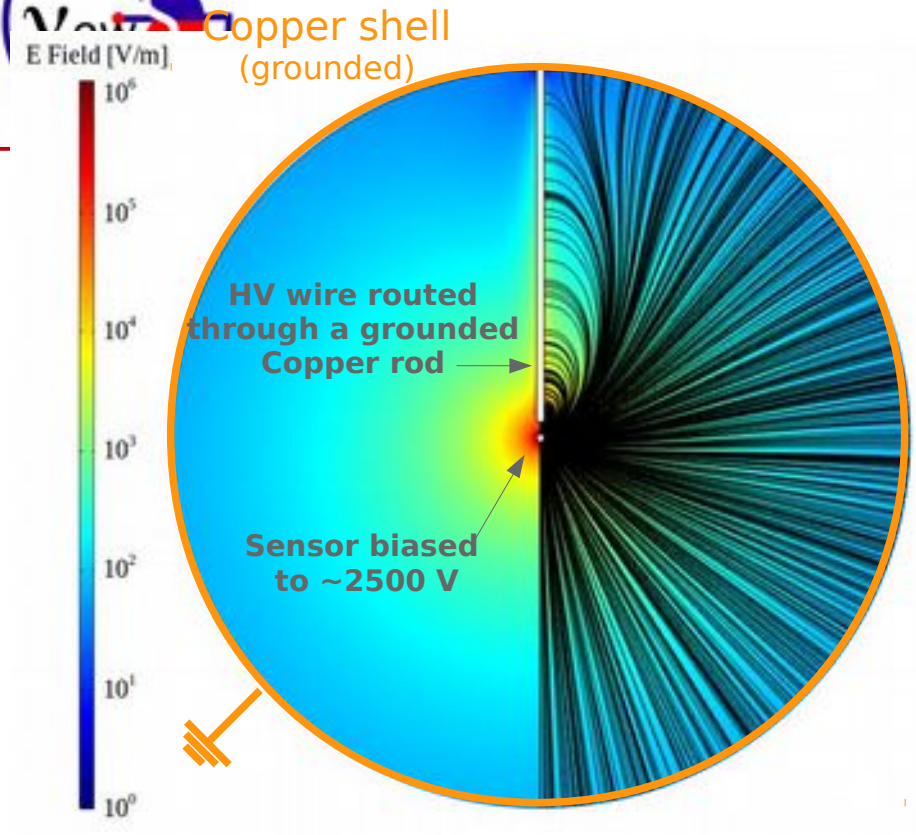
Associated lab : TRIUMF - F Retiere
- Future R&D on light detection, sensor

Backup

SPC signal


Induced charge
induced charge [a.u]
Induced current
induced current [a.u]
Integrated signal
integrated signal [a.u]
time [µs]

Light dark matter search with Spherical Proportional Counters (SPCs)



Vessel
60 cm ∅ NOSV Copper

Sensor
6.3 mm ∅

Sensitivity to single electrons

Low energy thresholds of 10 - 40 eVee

High amplification gain arising from $E(r) \propto \frac{1}{r^2}$

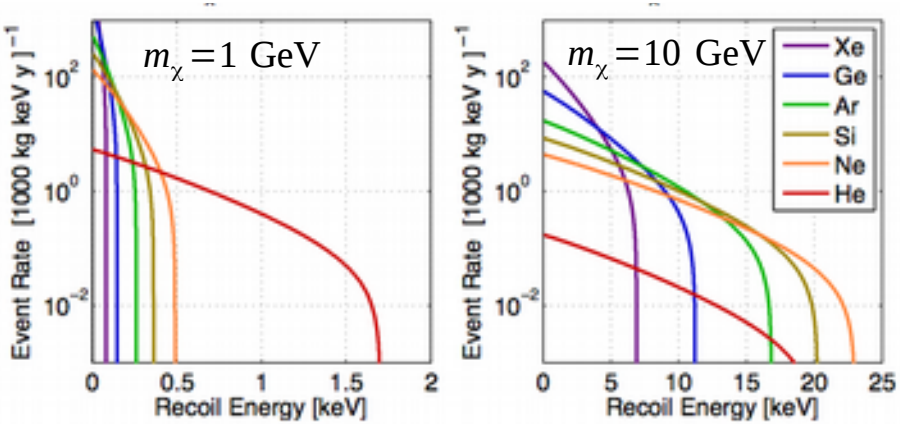
Low intrinsic capacitance (independent on the size of the sphere

Easily scalable

$$C = \frac{4\pi\epsilon}{\left(\frac{1}{r_{sensor}} + \frac{1}{r_{vessel}}\right)} \approx 4\pi\epsilon r_{sensor} \approx 0.35\,\mathrm{pF}$$

Light Targets (H,He,Ne)

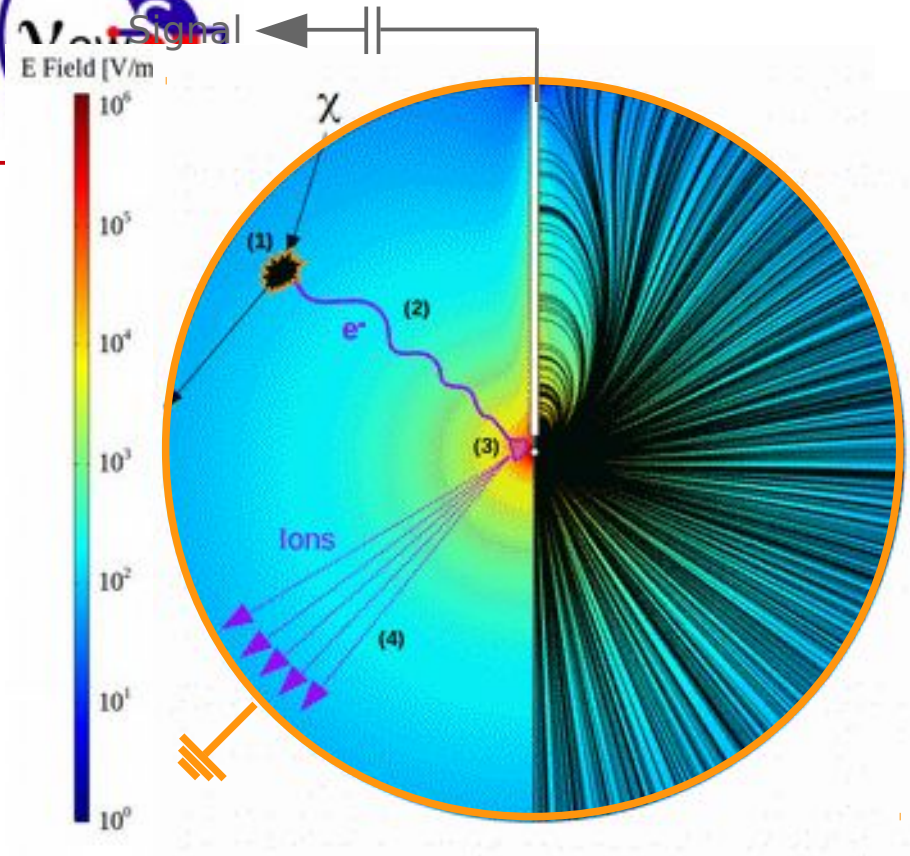
Optimization of momentum transfers for low-mass particles



Pulse shape discrimination

The rise time of pulses allows for a statistical discrimination against sub-keV surface events

SPC functionning principle in a nutshell



(1) Primary Ionization

Mean energy to create one paire in Ne :

$$\epsilon_\gamma = 36 \text{ eV} \qquad \epsilon_n = \frac{\epsilon_\gamma}{Q(E_R)} \approx 5\,\epsilon_\gamma$$

(2) Drift of the primary electrons towards the sensor

Typical drift time surface → sensor : ~ 500 µs

(3) Avalanche process

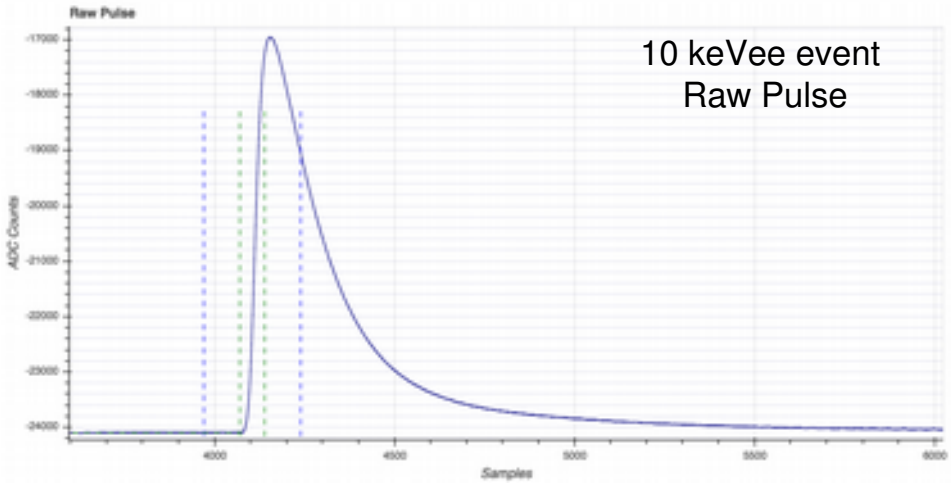
Thousands of secondary electron-Ion pairs / primary electron reaching the sensor

(4) Signal formation

Current induced by the ions as they drift back towards the copper shell at ground

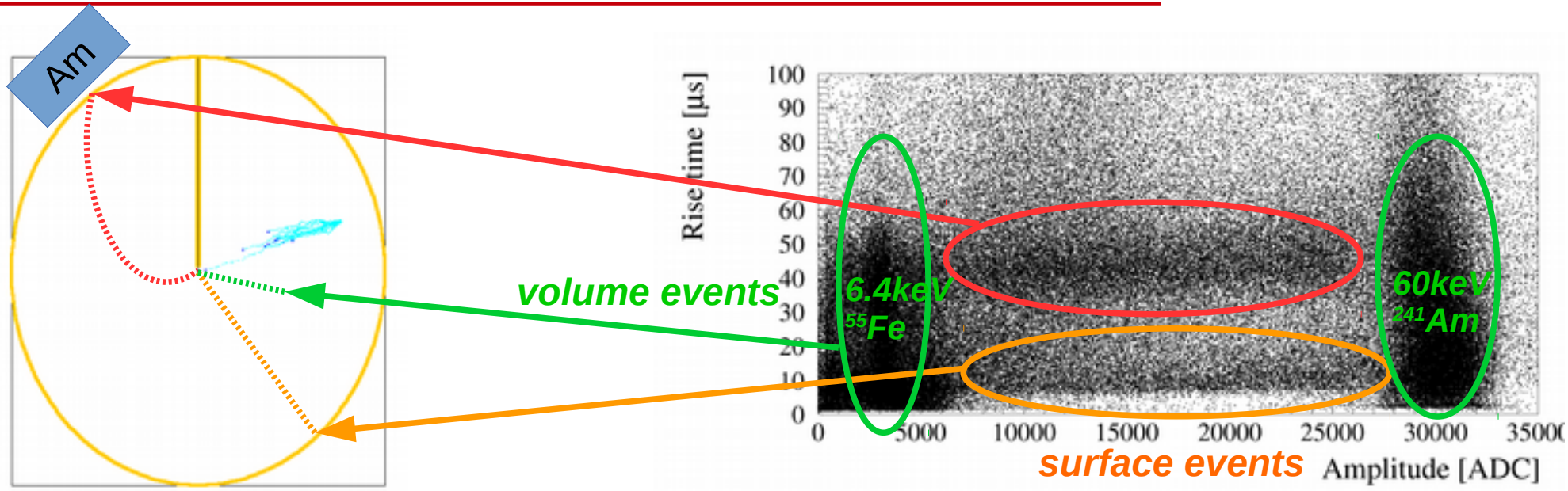
(5) Read out

Induced current integrated by a resistive feedback charge sensitive pre-amplifier CAMBERRA (RC=50 **µ**s) and digitized at 2.08 MHz

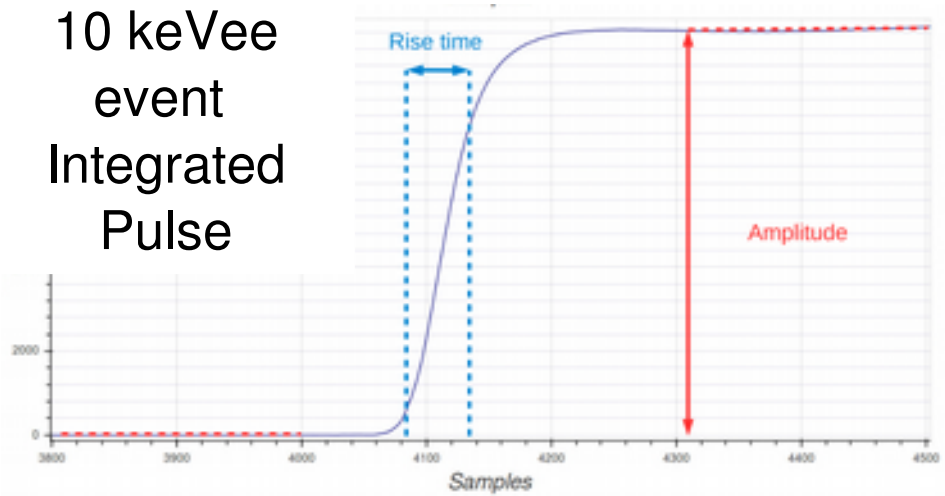


10 keVee event
Raw Pulse

Event discrimination: Rise time



10 keVee event Integrated Pulse



- Rise time ↔ Diffusion
- Discriminate long drifts (surface events)